CTEQ SUMMER SCHOOL 2004

Draft, 16 January 2004, DES

Overview of Perturbative QCD

8 hours

[4 hr.] **Introduction to the parton model and perturbative QCD**

Possible speakers: Sterman

[1 hr.] **Deeply inelastic scattering**

Links to *Nucleon form factors and structure functions.*

Possible speakers: Tung

[1 hr.] **Electroweak boson production in hadron collisions**

Links to *Lepton pair and weak boson production.*

Possible speakers: Owens

[1 hr.] **Production and evolution of high energy jets**

Links to *Jets at the TeV scale.*

Possible speakers: Huston

[1 hr.] **Heavy quark production**

Links to *Theory and experiment for heavy quark production.*

Possible speakers: Qiu

Applications

3-4 hr. each, 24 total hours

- *Nucleon structure* (Morfin)

– [1 hr.] **Models of the nucleon and chiral symmetry**

Quark model of the nucleon; bag model; chiral symmetry and chiral effective field theory, models of the nucleon based on chiral symmetry.

Possible speakers: Maxim Polyakov [Venugopalan recommendation] (U. Liege), Tony Thomas, Wally Melnitchouck. [D.E.S. comment: I have no idea who is better here]

– [1 hr.] **Nucleon form factors and structure functions**

GE, GM, axial vector, elastic scattering, transition form factors and nucleon resonance production, Q^2 behavior of form factors, transition from non-perturbative to perturbative QCD (precocious scaling, quark-hadron duality, large x and low Q^2 evolution), structure functions (spin averaged, spin-dependent, xF_3), structure function moments and sum rules. Note that the DIS introductory topic will have provided an introduction to F_1 and F_2.

Possible speakers: Rolf Ent, Don Geesaman (but he has major administrative responsibilities at ANL). [D.E.S. comment: Rolf Ent]

– [1 hr.] **Parton distribution functions**

Definition of the parton distribution functions as operator matrix elements; qualitative understanding with a large x emphasis; fragmentation functions; generalized parton distributions (theory, idea, as well as how to probe via deeply virtual Compton scattering, exclusive reactions); spin-flavor decomposition of the nucleon (Δs, Δg, semi-inclusive scattering); polarization observables, including transversity.

Possible speakers: Ed Kinney, Jen-Chieh Peng, Naomi Makins, or someone with a high energy physics background such as Robert Thorne. [D.E.S. comment: one of the first three, I suppose, but I don't know which one.]

– [1 hr.] **Factorization and its modifications**

Why factorization works at all; nuclear effects (modifications to form factors, structure functions and fragmentation functions)

hadron-formation length color transparency higher twist effects as $x \to 1$. Links to *Jets and energy flow in nuclear media.*

Possible speakers: Antje Bruell, Don Geesaman (but he has major administrative responsibilities at ANL). [D.E.S. comment: Antje Bruell]

- *Soft partons* (Sterman)
  - [1 hr.] **Small-x in DIS**

    Increasing parton density for $x \to 0$, possible breakdown of the perturbative approach; evolution in x (BFKL) instead of Q^2 as a tool for understanding this. Evidence from experiments at HERA.

    Possible speakers: Al Mueller, Gavin Salam [Venugopalan recommendation] (Paris), H. Kowalsky; Wesley Smith; or for a theorist, Kovchegov. [D.E.S. comment: I propose to first see if Al Mueller would like to give two of the second two lectures in this category, then decide on what to do with this lecture.]
  - [1 hr.] **Diffraction**

    Elastic scattering, diffractive cross sections; black/grey disk picture; pomeron phenomenology; diffraction with hard scattering; experimental results from HERA and Fermilab.

    Possible speakers: as above, Yuri Kovchegov [Venugopalan recommendation]; [D.E.S. comment: First ask Al Mueller.]
  - [1 hr.] **Models of saturation**

    Models beyond BFKL for what happens in small x-experiments when the effective gluon density becomes very high.

    Possible speakers: as above + Venugopalan, McLerran, Al Mueller [Venugopalan recommendation]. [D.E.S. comment: First ask Al Mueller.]
- *Jets and their evolution* (Sterman)
  - [1 hr.] **Jets at the TeV scale**

Jets as a probe of very short distances. QCD, electroweak, and beyond-Standard-Model sources of jets; jet definitions. Links to *Beyond the Standard Model*.

Possible speakers: Joey Huston.

– [1 hr.] **Jet substructure from e^+e^- annihilation**

Fractal nature of QCD jets; particle density in z in jets; differences between quark and gluon jets. Links to *Basics of event generators*.

Possible speakers: Bill Gary.

– [1 hr.] **Jets and energy flow in nuclear media**

Leading particles and energy loss through bremsstrahlung in collisions with nuclear matter; jet quenching. Links to *Event generators for heavy ion physics*.

Possible speakers: Rolf Baier [Venugopalan recommendation], Urs Wiedemann [Venugopalan recommendation] [D.E.S. comment: I don't have a preference between these.]

- *Heavy quark and quarkonium physics* (Qiu)

  – [1 hr.] **Theory and experiment for heavy quark production**

  Discovery of the top quark at the Tevatron; Top production in current Tevatron runs; Bottom quark production at Tevatron. We should be able to manage this in one hour because we have a one hour introductory talk on this also.

  Possible speakers: Michelangelo Mangano; Keith Ellis of FNAL is not too far away from Madison, while from CTEQ, Fred Olness has lectured on this topic and Ed Berger might be another candidate. [D.E.S. comment: I would be inclined to ask Mangano first.]

  – [1 hr.] **Heavy quarkonium production**

  Production mechanism for heavy quarkonia; Color evaporation model; NRQCD approach (color singlet and octet channels); Quarkonium p_T distributions and polarization at the Tevatron.

  Possible speakers: Tom Lecompte (ANL) [S.K.] ; [D.E.S. comment: Lecompt]

– [1 hr.] **Charm production in a nuclear medium**

J/psi production in nuclear medium; J/psi suppression as a potential signal of QGP; charm production in medium and the "dead cone" effect in energy loss.

Possible speakers: Outside of CTEQ, one might consider Dima Kharzeev of BNL, who worked with Satz on J/psi suppression for years, and is a good speaker. Within CTEQ, Qiu is familiar with this topic, having worked on this himself. (DES comment: we want someone who can be sufficiently critical. Venugopalan comment: either Kharzeev or Qiu), Tom Lecompte (ANL) [S.K.]; [D.E.S. comment: Lecompte]

- *New physics at colliders* (Zeppenfeld).

  – [1 hr.] **Beyond the Standard Model**

  Expectations for what physics might exist beyond the Standard model along with experimental signatures for the new physics.

  Possible speakers: Tao Han, Stephen Martin, Jim Wells, or maybe Arkani-Hamed. [D.E.S. comment: I asked Zeppenfeld to see if Tao Han is interested. After that, I would be inclined to give Arkani-Hamed a shot.]

  – [2 hr.] **Higgs physics and QCD**

  How to find the Higgs boson, including the QCD knowledge necessary for the search.

  Possible speakers: Sally Dawson, Dieter Zeppenfeld, Michael Kramer. [D.E.S. comment: Sally Dawson would be my first choice.]

  – [1 hr.] **Single top production**

  Single top quark production as probe of W-t couplings and as a signal for new physics.

  Possible speakers: C. P. Yuan, Scott Willenbrock [D.E.S. comment: C. P. Yuan would be my first choice.]

- *Electroweak vector bosons* (Owens)

– [1 hr.] **Lepton pair and weak boson production**

Theory and experiment for γ^*, W, Z production including discussion of the possible use of these cross sections for fixing the luminosity at the LHC, the NNLO predictions for the cross sections, and summation of logs for the P_T distribution. One hour should be sufficient since there is an introductory lecture on this topic.

Possible speakers: Owens has lectures from the 98 and 00 schools which treat the lepton pair and weak boson topics. Fred Olness has a two lecture set on lepton pair and weak boson production from this year. Or we might try W. Vogelsang. [D.E.S. comment: my inclination is to try Vogelsang.]

– [1 hr.] **Direct photon production**

Theory and experiment highlighting the differences in production mechanism compared to W, Z production; separation of the fragmentation and π decay components.

Possible speakers: Jeff Owens and Steve Kuhlmann each have material to cover the photon lecture. [D.E.S. comment: Owens]

– [1 hr.] **W, Z and direct γ production as a probe in nuclear collisions**

Both lepton pair and photon signals are topical as regards the RHIC program. One hour should be sufficient given the introductory material from the previous lectures.

Possible speakers: Werner Vogelsang comes to mind since he is involved with the RHIC program and has experience with photons. [D.E.S. comment: Vogelsang]

- *Event generators/parton level Monte Carlos* (Kuhlmann)

– [1 hr.] **Basics of Event Generators**

An introduction to how a generic Monte Carlo event generator works. This is a bit skimpy with respect to time, but we can make use of the previous knowledge from the jet substructure topic.

Possible speakers: Steve Mrenna. [D.E.S. comment: Mrenna is the obvious choice.]

– [1 hr.] **Tests of Event Generators at the TeV Scale**

Pythia and Herwig compared to data.

Possible speakers: Mrenna, Rick Field or an experimentalist; ask Joey Huston for suggestions. [D.E.S. comment: then Mrenna could continue with a comparison.]

– [1 hr.] **Event generators for heavy ion physics**

What is used now and a critique of the existing tools. (Comment: the original topic was event generators for spin *and* heavy ion physics. However, these are quite different topics, so I picked one. DES)

Possible speakers: Jamie Nagle [Venugopalan recommendation]; Xin-Nian Wang (LBL), who is coauthor with Gyulassy of the Hijing code; Jamie Nagle. [D.E.S. comment: I would follow Venugopalan's recommendation and choose Nagle.]

– [1 hr.] **NLO tools for colliders**

Next-to-leading parton level Monte Carlo tools, what goes into them and how to use them. (This is transferred from Zeppenfeld's section, reduced in time allotment.)

Possible speakers: Kieth Ellis, Stefano Catani, Carlo Oleari, John Campell. [D.E.S. comment: Keith Ellis would be an obvious choice.]